TCAD Analysis of Silicon-Germanium (SiGe) based Back-Contact Back-Junction (BC-BJ) solar cell as an alternative for silicon based cells

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ABSTRACT

In this work, an ultra-thin, Back-Contact Back-Junction (BC-BJ) Silicon-Germanium (SiGe) solar cell device structure called BC-BJ SiGe solar cell has been proposed, which shows enhanced photovoltaic properties, External Quantum Efficiency (EQE) > 76% in the spectrum range of 400-700 nm wavelength have been achieved. Results further, reveal that proposed device is less affected by carrier recombination, resulting in 13.5 % power conversion efficiency (PCE). Also we obtained the impact of material thickness on device parameters and we found that the 5µm thick SiGe cell is as efficient as 10µm thick silicon cell. The PCE of 5µm thick SiGe cell and 10µm thick silicon cell was 11.3% and 11.8%, respectively. It indicates that the proposed device significantly save the material cost over the silicon cell. All the simulations have been done using DEVEDIT and ATLAS device simulator.

Keywords: Efficiency, Recombination, Silicon-Germanim, Solar cell

1 INTRODUCTION

Crystalline silicon is the largest component of the solar photovoltaic (PV) cells. Over 80% installed solar PV in 2011 used silicon as their largest material. Silicon is widely used material for PV due to its reliability, abundance, and mature fabrication process. In Silicon PV technology, absorption coefficient of Silicon is small, to absorb enough of the solar cell spectrum. The thickness of conventional silicon cell is typically more than 100µm, in order to absorb the solar spectrum. Now since, thickness is large, in order to collect light generated carrier, minority carrier lifetime must be high enough and the recombination coefficient should be low. This requirement of large volume and high quality silicon significantly increases the module cost. In order to make photovoltaic system feasible at large scale, it should be cost effective, with module cost to be < $0.5/W [1]. In this paper, we proposed SiGe as an alternative to silicon solar cell, due to its higher minority carrier lifetime and lower recombination coefficient. Reducing the thickness of PV materials used in solar cell production is a major goal of solar cell industry, due to its fruitful contribution to the overall cost of a PV system. However, thin silicon cells are not effective, due to severe Auger recombination and increased surface to volume ratio [2].

One promising high-efficiency solar cell concept is the back-contact back- junction solar cell [3, 4] having both, junction and the electrodes at back side of the device. Now, since the junction and contacts are at the back side, Front surface can be designed for optimum optical performance [5].

Here, we proposed novel 10µm thick crystalline SiGe back-contact back-junction solar cell, which overcomes the critical problems of thin devices: Auger and surface recombination etc. Further, we have obtained the impact of material thickness on photovoltaic parameters. In SiGe technology the electrical properties of silicon are modified with germanium. SiGe processing is simple because the physical and electrical properties of silicon and germanium are similar [6]. Also SiGe possesses higher mechanical strength, and suppresses the high intensity degradation of solar cell under illumination [7]. Optical absorption of SiGe can further be modified by varying Ge content [8, 9].

2 DEVICE STRUCTURE AND PHYSICAL MODELS

Silvaco ATLAS used to simulate the device optoelectronic characteristics. ATLAS is a device simulator capable of modeling the electrical, thermal, and optical characteristics of semiconductor devices.

In the simulation, we assume a two dimensional structure, BC-BJ solar cell as shown in Fig. 1. The $Si_{0.9}Ge_{0.1}$ was used during the simulation, very small fraction of germanium is used. Because, if we increase the germanium content the bandgap of SiGe decreases [10] The substrate was N-type, with doping density of $3x10^{15}$ cm^{-3}, whereas N+/P+ region has the doping density of $4x10^{20}$ cm^{-3}. The depth of P+ and N+ region was 3µm and 2.5µm, respectively, whereas the width was 40µm and 30µm, respectively. The Nitride (Si_3N_4) is used as anti-reflecting front surface passivation, and modeled as an optical layer with the thickness of 70 nm. The Oxide (SiO_2) is used as back surface passivation with thickness of 50nm.

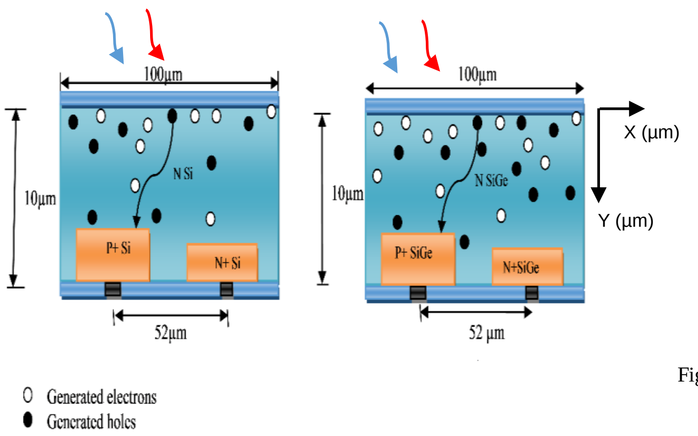


Fig.1. Simulated device: - 10µm thick BC-BJ solar cell: (a) Silicon (b) SiGe

To obtain the J-V curve under illumination, we used the standard AM1.5 solar spectrum, divided into 400 points. The models used in the simulation assume a concentration dependent mobility using default software values for electron and holes [11]. Shockley – Read-Hall and Auger recombination mechanisms were taking into account. Auger recombination was modeled with the default software values of Auger coefficient 2.8×10^{-32} cm^6s^{-1} for electrons and 9.9×10^{-32} cm^6s^{-1} for holes, in case of silicon, whereas 9.9×10^{-31} cm^6s^{-1} for electrons and 1.8×10^{-31} cm^6s^{-1} for holes were used, in case of SiGe. The minority carrier lifetime of 10^{-6}s and 10^{-5}s has been used for silicon and SiGe, respectively. The Poisson equation together with the continuity equation for electrons and holes are solved simultaneously by the software to obtain the J-V characteristics.

3 SIMULATION RESULTS

Figure 2 shows the contour plot of recombination rate. The magnitude of recombination rate in silicon cell is in the order of (10^{20} /cm^3s), whereas in proposed device it is (10^{18} /cm^3s).

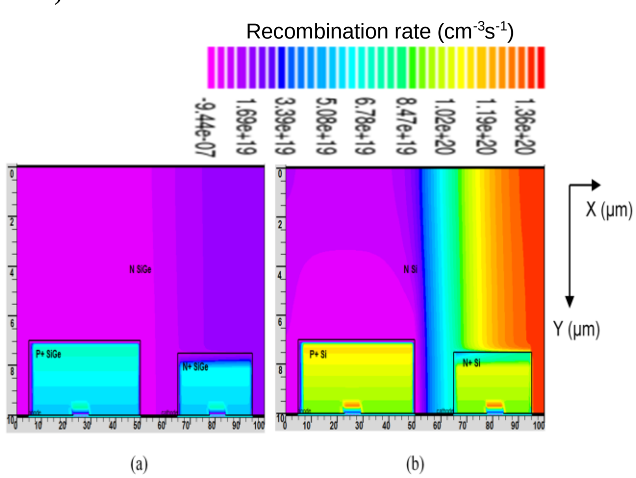


Fig. 2. Recombination rate contour (logarithmic plot): (a) 10µm thick BC-BJ SiGe solar cell (b) 10µm thick BC-BJ Si solar cell.

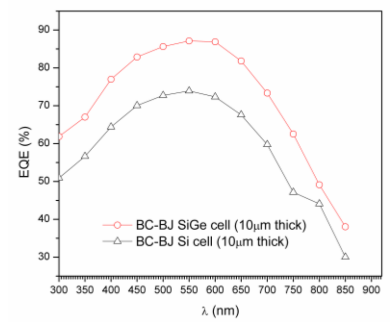
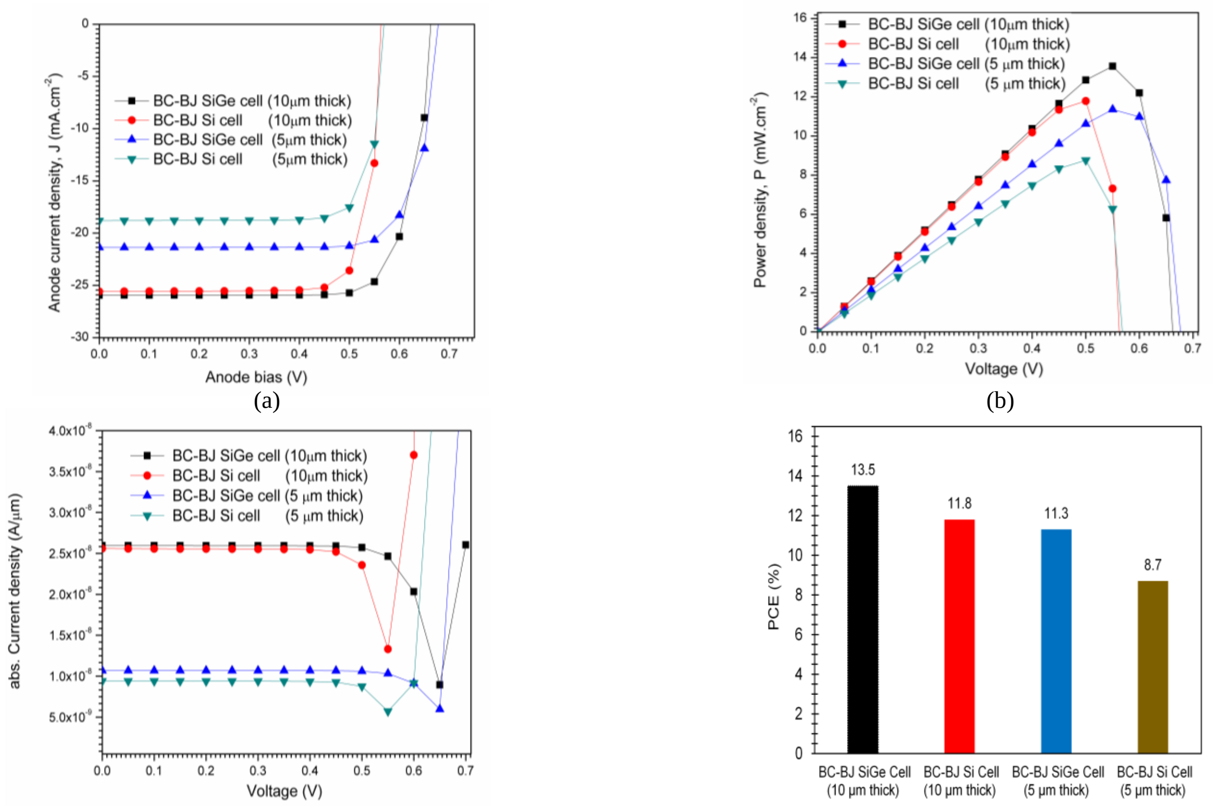


Fig. 3. Comparison of External Quantum Efficiency (EQE)

At the interface, recombination rate is higher in right side of the devices because collection probabilty of minority carriers (hole) is decreases. The lower recombination is observed in novel device because minority carrier lifetime is higher compared to silicon cell. In back contact design, most of the carriers are generated near the front surface, while the junction is far at the back surface. Lower recombination ensure higher carrier collection efficiency.

Also, the EQE of the proposed device is higher than silicon cell as shown in Fig 3. The proposed device shows EQE>76% in the spectrum range of 400-700 nm wavelength whereas in silicon cell, EQE>60% was obtained. The proposed device shows 26% higher EQE compared to silicon cell, due to the presence of Ge. Since, the no. of free electrons in the germanium is higher than the silicon at given temperature, which results in higher conductivity of Ge.

Further, we have obtained the impact of device thickness on photovoltaic parameters. We have decreased the device dimension to half the initial dimensions, discussed earlier, keeping the aspect ratio (Width/Depth) of P+ and N+ region fixed 1/15 and 1/12, respectively. The length of the pitch becomes 26µm. The electrical parameters of 10µm thick devices and 5µm thick devices are plotted in Fig 4. Fig. 4(a&d), shows the current density-volatge (J-V) curve and PCE bar for different devices, when thickness of silicon cell decreased from 10µm to 5µm, change in short circuit current density J_{SC} and PCE was 26.6% and 26.2%, respectively, whereas for SiGe it was 17.7% and 16.3%, respectively. It shows that proposed device is less affected by the thickness variation compared to the conventional silicon cell. Also Fig. 4(b&d) shows that the maximum output power density (P_M) of 10µm thick silicon cell and 5µm thick SiGe cell was approximately same, 11.8mW/cm^2 in 10µm thick silicon cell and 11.3mW/cm^2 in 5µm thick SiGe cell, respectively. Also, open circuit volatge (V_{OC}) can be obtained by taking the intercept to x- axis form the sharp minima, shown in Fig. 4c. Proposed device shows superior photovoltaic properties comparing to conventional silicon cell due to lower recombination [12]. Detailed comparisons of electrical parameters are shown in Table 1. Table 1, shows that the performance of 5µm thick SiGe was approximately equal to the 10µm thick silicon cell, indicating that the proposed device significantly saves the material cost over silicon cell.



(a) (b)

(c) (d)

Fig.4. Comparisons of electrical characteristics of different devices: (a) J-V, (b) Power density-voltage, (c) Abs.current density-voltage (d) PCE.

Table1. Detailed comparisons of electrical parameters

Device	Voc (V)	Jsc ($mAcm^{-2}$)	FF (%)	PCE (%)
Silicon cell (10μm thick)	0.563	25.6	81.8	11.8
SiGe cell (10μm thick)	0.663	25.9	78.8	13.5
Silicon cell (5μm thick)	0.569	18.8	81.9	8.7
SiGe cell (5μm thick)	0.677	21.3	78.4	11.3
FF-fill factor, PCE- power conversion Efficiency.				

4 CONCLUSION

In this work, we proposed a novel 10μm thick BC-BJ SiGe Solar cell design, as a cost-effective solution for energy efficient applications. The work analyse and compares the optical and electrical characteristics of proposed design using Silvaco Atlas device simulator.

Proposed device shows superior photovoltaic parameters compared to silicon cell. Also results reveal that when the thickness of proposed device is reduced to 5μm, its PCE, 11.3% was approximately equal to PCE, 11.8% of 10μm thick silicon cell. It indicates that the proposed device significantly saves the material cost over silicon cell. Proposed device shows improved photovoltaic parameters: EQE> 76% in the spectrum range of 400-700 nm wavelength, Jsc 25.9$mAcm^{-2}$, Voc 663mV, fill factor (FF) 78.8% and PCE of 13.5%. Simulation result shows SiGe semiconductor as an alternative to expensive materials for thin BC-BJ solar cell design.

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REFERENCES

[1] S. Jeong, M. D. McGehee and Y. Cui , "All-back-contact ultra-thin silicon nanocone solar cells with 13.7% power conversion efficiency" Nature Communications 4, Article number: 2950: 1-7, 2013.

[2] R. R. King, R. A. Sinton, and R. M. Swanson, Studies of diffused phosphorus emitters: saturation current, surface recombination velocity, and quantum efficiency. IEEE Trans. Electron Dev. 37, 365–371, 1990.

[3] R. J. Schwartz and M. D. Lammert. Silicon solar cells for high concentration applications. In IEEE International Electron Devices Meeting, pages 350–352, 1975.

[4] E. V. Kerschaver and G. Beaucarne. Back-contact solar cells: A review Progress in Photovoltaics, 14(2):107–123, 2006.

[5] D.diouf, J.P. Kleider, T.desrues, P.-J. Ribeyron" Study of interdigitated back contact silicon heterojunction solar cells by two-dimensional numerical simulations", Material Science and Engineering B 159-160:291-294. 2009

[6] J.Ouellete,"Silicon-Germanium Gives Semiconductor the Edge" American institute of physics, 2002:22-25.

[7] D.Yang, X.Yu, X. Li, P.Wang, L. Wang, "Germanium-doped crystal silicon for solar cells," Solid-State and Integrated Circuit Technology (ICSICT), 2010 10th IEEE International Conference on, vol., no.,1994,1994, 1-4 Nov. 2010.

[8] C.C.Wang, D.S.Wuu, S.Y. Lien, Y.S. Lin, C.Y. Liu, C.H. Hsu, and C.F. Chen , "Characterization of Nanocrystalline SiGe Thin Film Solar Cell with Double Graded-Dead Absorption Layer " International Journal of Photoenergy Volume 2012, 6 pages

[9] H. Povolny, P. Agarwal, S. Han, and X. Deng, "Comparison Study of a-SiGe Solar Cells and Materials Deposited Using Different Hydrogen Dilution " Mat. Res. Soc. Symp. Proc. Vol. 609, 2000.

[10] G.G. Pethuraja et al., Materials Sciences and Applications, 3, pp.67-71, 2012.

[11] ATLAS User's Manual DEVICE SIMULATION SOFTWARE. May 17, 2012.324.

[12] S.M.Sze," Physics of Semiconductor Devices 2nd Edition": 811-813